Maxwell's equations revisited

A critique of orthodox electromagnetic theory

by Ivor Catt, CAM Consultants

"It was once told as a good joke upon a mathematician that the poor man went mad and mistook his symbols for realities; as M for the moon and S for the sun."

Oliver Heaviside, Electromagnetic Theory, 1893, volume 1, page 133.

". . . the universe appears to have been designed by a pure mathematician."

Sir James Jeans, The Mysterious Universe, 1931, page 115.

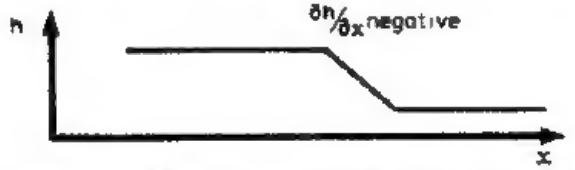
Faraday's Law of Induction, $v = -d\phi/dt$, seems to imply:

1. A causality relationship; the rate of change of magnetic flux through a surface *causes* a voltage around the circumference of the surface.
2. A reluctance, or resistance to the change of magnetic flux indicated by the minus sign.

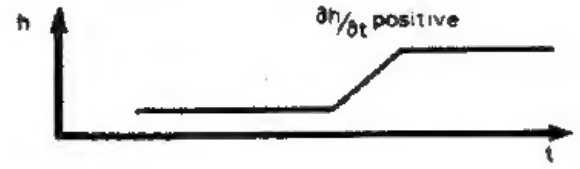
A careful analysis of this one equation will give an insight into the bogus nature of contemporary mathematical operations in electromagnetic theory.

First let us discuss the minus sign, which leads us to the idea of a Lenz's Law reluctance, or resistance, to the change $d\phi/dt$. We shall see that a minus sign can occur in an equation when no causality can be involved.

Consider a high speed (125) railway train with sloping front passing an observer. As the front face passes, the observer will see a negative slope $\partial h/\partial x$ as shown below. However, if the



observer had watched the event through a narrow slit in a fence, he would have seen a rising edge $\partial h/\partial t$, as shown here.



It would be absurd to suggest that there was a causality relationship between $\partial h/\partial x$ and $\partial h/\partial t$. They are both descriptions associated with the passage of the train. Since Newton, it is accepted that a *body* continues in its

state of uniform motion without a continuing cause, or push. (However, this principle is taking a long time to be applied to electromagnetic waves.)[1,2]

Now we regard the velocity of the train $\partial x/\partial t$ as positive. This creates an anomaly when we want to write the equation

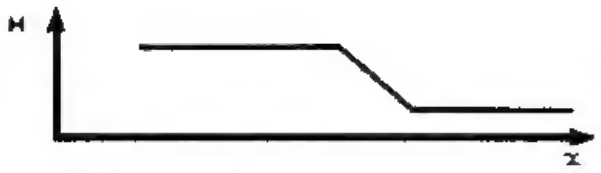
$$\frac{\partial h}{\partial x}\cdot\frac{dx}{dt}=\frac{\partial h}{\partial t} \qquad (1)$$

because the left hand side product is negative when the right hand side is positive, as in the case of the leading face of the train.

This kind of absurdity, or anomaly, is ignored when Newton's Laws are considered. It is reasonable to do so, because Newton's Laws are close to common sense and the obvious. Common sense will prevent absurd conclusions from creeping into a Newtonian theoretical framework, even though the mathematical formulation of Newton's Laws has always been slovenly in this respect.* (Another perhaps permissible slovenly aspect is the use of the = sign for numerous different, mutually contradictory meanings.)

Maxwell's Equations are not in the same class. Common sense will not save us from absurdity and nonsense if our initial formulations are ambiguous or wrong.

Let us consider an electromagnetic wave front advancing at the speed of light. When the step (or more accurately ramp) passes, as shown here



$\partial H/\partial x$ is negative. However, $\partial H/\partial t$ for the step is positive. To get the algebra right, we are forced to conclude that

$$\frac{\partial H}{\partial x}\cdot\frac{dx}{dt}=-\frac{\partial H}{\partial t} \qquad (2)$$

However, no one would propose that the minus sign indicated a *causality* relationship between $\partial H/\partial x$ and $\partial H/\partial t$.

The last equation never appears in the text books. In the books, one of the terms is first converted into a function of E according to the formula

$$\frac{E}{H}=\sqrt{\frac{\mu}{\epsilon}}$$

The result is either

$$\frac{\partial E}{\partial x}=-\frac{\partial B}{\partial t} \qquad (3)$$

or

$$\frac{\partial H}{\partial x}=-\frac{\partial D}{\partial t} \qquad (4)$$

The text books say the "solution" to this pair of equations is a sine wave! See references 3 to 7. (In fact, almost anything is a solution to these equations.)

At this stage, the whole subject starts to look sophisticated and profound. Really it is neither. The minus signs have no significance, as we have seen. B and D are introduced on the r.h.s merely to suppress μ and ϵ using the formula

* Even the brilliant philosopher Ernst Mach failed to notice this anomaly.

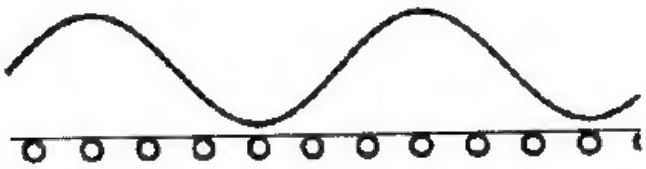
$$\frac{E}{H} = \sqrt{\frac{\mu}{\epsilon}}$$

In fact, the last two equations (3), (4) are meaningless. If the front end of the high speed train were pointed, sloping out sideways as well as upwards, and w were the term given to width (as H stands for height), exactly the same pair of equations could be constructed.

$$\frac{\partial w}{\partial x} = -\mu \frac{\partial H}{\partial t}$$

$$\frac{\partial H}{\partial x} = -\epsilon \frac{\partial w}{\partial t}$$

As with e-m theory, we could conclude with equal validity that a train's height (and width) must vary sinusoidally along its length, making our trains look like the Loch Ness monster, or more accurately, like a row of short sausages, as shown here.



It is shocking that this nonsense has survived for a century at the core of a subject as crucial as electromagnetic theory. We see now that mathematical formulation of e-m theory, far from making the subject more rigorous, has made it ludicrous and false. We see that the mathematicians are incompetent where physical reality is concerned and hide their incompetence and confuse others by conjuring up nonsensical, interrelated formulae.

When Hertz established that electromagnetic waves existed, Maxwell's equations should have been re-examined, and the large rubbish element removed. Instead physically ignorant mathematicians took over, piling garbage on garbage, frightening away those with real insight into the subject – the latter-day Faradays.

Those who try to build extensions, or additions to, the House of Newton should not assume that since the foundations were good enough for Newton's simpler theory, they are strong enough to support their own more complex constuctions. Minkowski's failure to re-examine the foundations of Newton, in particular his assumption that velocity is positive and the passage of time is positive, makes his constructions useless in the same way as Maxwell's equations are useless.

In the Minkowski sense[8] time really flows from $+\infty$ to $-\infty$, not, as he thought (and our clock faces, with their ascending sequence of numbers, think), from $-\infty$ to $+\infty$. Velocity, being the gaining of distance in return for the *loss* of time, is negative. This points to a fundamental difference between space and time, and means that the "space-time continuum" as Minkowski formulated it is bogus. At best, we see his pronouncements as oracular, similar to the answer that Delphos gave when being asked about the sex of an unborn child, "Girlnoboy". This remark could well be interpreted as true, but really it has no content.

Einstein failed to consider the problem of the sign of time and of velocity. Also[9], he never succeeded in fighting his way through the mass of mathematical garbage surrounding electromagnetic theory.

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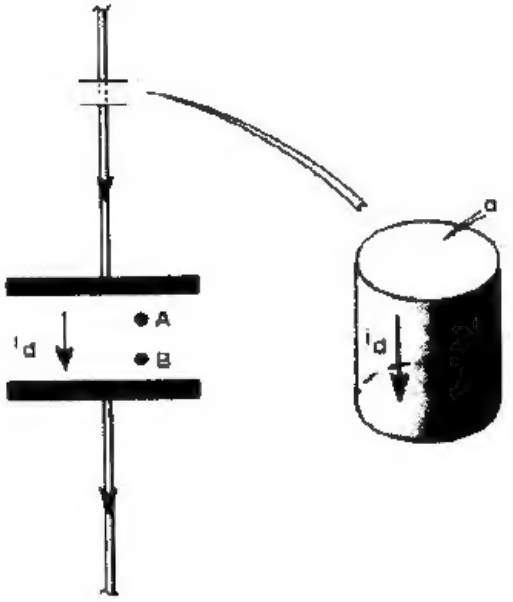
WIRELESS WORLD, APRIL 1980

DISPLACEMENT CURRENT

In the articles on displacement current by Catt, Davidson, and Walton (Dec 1978, March 1979) two important concepts are brought out. One is the limitations of Maxwell's lumped capacitance model, the other the transmission-line model the authors have contributed. However, the authors' claim with reference to Maxwell's capacitor that the displacement current is "an artefact of this faulty model" should be taken with a grain of salt. Maxwell's displacement current occurs at many places and in many forms, one of which is inside a capacitor, another in free space. Whether or not the authors replace Maxwell's capacitor with a transmission line has nothing to do with dD/dt in space, which will forever continue to make electromagnetic wave propagation possible, whatever is the source.

It is stated repeatedly that charge flows, which is correct, but also that current "flows". Current is a time-rate quantity that *exists* or *is*; it does not flow. *It reflects a point observation*, how much charge that passes that point. If no charge is passing there is no current. It is particularly hard to consider current "flowing" when it is a displacement current, appearing where there are no moving charges. In the accompanying diagram no charges move between points A and B, or anywhere between the two capacitor plates.



The displacement current is no current at all, because we have robbed it of the very agent it needs to be a current – the flow of charge. Is it sensible to talk about "flowing currents" in vacuum? So, both "flow" and "current" are objectionable terms, notwithstanding the fact that i_d is a current, equal to the conduction current i both to quantity and unit. It is unfortunate that Maxwell did not call his displacement current something else, such as "displacement entity".

Some experts on electromagnetic theory do not use the historically inherited terms "displacement" and "displacement current" at all, while they do employ Maxwell's math

and give proper credit to Maxwell [1]. Why are we so disturbed about names we can do without, holding on to the math? The title of the authors' first article was "Displacement Current – and how to get rid of it". If someone really succeeds to get rid of displacement current in Maxwell's capacitor, and then opens up the plates so that it becomes an antenna, how comforting it must be to this person to learn that wireless communication is just a fiction of the mind. And to the authors who succeed in getting rid of the displacement current at the input to their transmission line, what a setback it must be to have to accept displacement current *inside* the transmission line. In their Fig. 3 in the second article, the quantity D is shown four times inside the transmission line. The moment the transmission line is put to use, D becomes dD/dt. The authors seem to imply that when displacement current occurs inside a transmission line, it need not be explained. The truth in the matter is that dD/dt in a transmission line requires the same amount of explanation as that in a capacitor, if not more, ie to the one who feels that he does not understand displacement current. To him, if Maxwell's displacement current in a capacitor begs for an explanation, so does the same thing when occurring in a transmission line. But the "paradox" of the capacitor is today a paradox for the layman only. Particularly with the extended theory the authors offer, the math of electromagnetism is clear and to the point. One cannot escape the impression that the author effort to get rid of the displacement current is not only futile, it is also misdirected!

If we accept the fact that electromagnetic waves are generated from an antenna, and if we get a number of wavelengths away from it, then

$$\nabla \times H = \nabla \times (B/\mu_v) = dD/dt = \epsilon_v\, dE/dt \qquad (1)$$

(partial derivations intended). This is a more crucial case to tackle for those who set out to get rid of Maxwell's displacement current. Just to mention another case of the omnipresence of this current, see the right-hand side of my diagram. There exists displacement current already in the wire that goes to the capacitor, such as a copper wire, because it has an E-field. Quite apart from the immensely much greater conduction current in the wire, it is likewise dependent on the area a. The point is that it is there. If we more or less successfully do away with displacement current in one place, should we not do away with it in all places? And the most important place of them all is that depicted by (1).

Certainly the authors are right in placing the electromagnetic energy in the fields, and they are justified in dressing up the capacitor as a transmission line, to which the old Maxwell capacitor presents a conditional approximation. But, what kind of a transmission line? In Maxwell's equation (1) in its general form

$$\Sigma(B/\mu_v)s = i_c + i_d = i_c + d\Phi/dt \qquad (2)$$

here written symbolically and simplified, s is the magnetic field-line path, i_c the conduction current, and Φ the electric flux. The equation shows that i_d has magnetic field, too. Nevertheless, the authors promote only a TEM magnetic field, turned 90° with reference to Maxwell's. The field situation is quite a complex one, with the boundaries extending to right-angle bends, and the entire capacitor with standing waves on the plates located inside the demarcation line of the Fresnel zone. Thus the vectors E and B are not necessarily normal to each other, nor does the E-field necessarily convey the same energy as the B-field. Theoretically at least, as a limit consideration, a certain magnetic field can be approximated out of existence because almost all the energy is in the E-field. From the authors' illustrations, it is hard to figure out how the magnetic field lines are supposed to go. Whatever TEM there is, it surely is not alone.

(1) is an interesting way of writing one of Maxwell's equations for free space. If we don't like D, we can use E. (And, if we don't like H, we can use B.) Perhaps the fact that D is not as important as it is made out to be should be brought out here. We might say

that Maxwell put D and H on a pedestal, and that history has given both quantities a lot of significance, while the really important quantities are E and B, at least to the engineer. Specifically, the two historically inherited equations are shown in (3),

$$D = \epsilon_v E \qquad B = \mu_v H \qquad (3)$$

$$E = (1/\epsilon_v) D \qquad B = \mu_v H \qquad (4)$$

We may claim that (3) is an anomaly since it tends to convey the general idea that there exists an important relationship, on one side between D and B, on the other between E and H. If so, (3) is deceiving, while (4) conveys the right idea. This is that E goes with B, and D with H. Perhaps also that D and H are less important (and thus explanations of D and dD/dt less important). Although we cannot do without them, we may consider D and H merely as aids in the unwinding of electromagnetic theory, stepping stones in the classroom teaching leading to E and B. We may look upon D and H as auxiliary quantities, with D tying q and E together (the electric tie, so that we can proceed from charge to field), and similarly H tying i and B together. Then dD/dt is simply the "tie rate". If we can make D and dD/t less important, on a relative scale, and give the engineer more appropriate names and concepts, it seems that the entire issue of the displacement current may have lost its edge.

H. E. Stockman
Sercolab
Arlington
Mass. USA

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1. King, R. W. P. "Fundamental Electromagnetic Theory", Dover, 1962.

The authors reply.

With regard to para 1, neither Maxwell nor anyone else except Dr Stockman has identified more than one form of Maxwell's displacement current, or asserted that dD/dt behaves in some way differently inside a capacitor and in free space. We anxiously await amplification of this important preliminary disclosure. We thought that, like the Cheshire Cat's grin, displacement current was always the same.

As to para. 2, where Dr Stockman suggests that "displacement current" should be renamed "displacement entity", we would prefer "displacement nonentity".

With regard to para. 3, we object to Maxwell's math quite as much as we object to his names. Further, the quantity D is not displacement current, as Dr Stockman avers. We do not object to the quantity D, which equals ϵE. In our Fig. 3, D does not imply the existence of a dD/dt. Quite the contrary, dD/dt is zero at three of the four points where D is written, although at each of those points an electromagnetic signal is successfully travelling along without the benefit of a non-zero dD/dt.

Now for para. 4. Let us tackle equation (1) in a world devoid of displacement current but containing TEM waves as defined in *Wireless World*, July 1979, page 73.

$$\text{LHS} = \nabla \times H = \text{curl } H = -\frac{\partial H}{\partial x} \qquad (1)$$

$$\text{RHS} = \epsilon \frac{dE}{dt} \qquad (2)$$

From definitions in the July 1979 issue, page 73

$$-\frac{\partial H}{\partial x} = \frac{1}{c}\frac{\partial H}{\partial t} \qquad (3)$$

by definition
(see *W.W.* July Appendix 1)

$$\text{Now since } \frac{E}{H} = \sqrt{\frac{\mu}{\epsilon}}, \quad D = \epsilon E, \qquad (4)$$

$$\frac{D}{\epsilon H} = \sqrt{\frac{\mu}{\epsilon}} \qquad (5)$$

$$\therefore D = \frac{H}{c} \qquad (6)$$

$$\therefore \frac{\partial D}{\partial t} = \frac{1}{c}\frac{\partial H}{\partial t} \qquad (7)$$

Therefore substituting in (3),

$$-\frac{\partial H}{\partial x}=\frac{\partial D}{\partial t}=\epsilon\frac{dE}{dt} \qquad (8)$$

Returning to (1),

$$\nabla\times H=\epsilon\frac{dE}{dt}$$

See, no displacement current!

Of course, these mathematical arpeggios, the likes of which have for so long masqueraded as electromagnetic theory, are quite meaningless and futile. We might as well be asked to demonstrate our skill at basket weaving (or at computing large prime numbers) in order to establish our credibility as experts in electromagnetic theory

Continuing with Dr Stockman's para. 4, there certainly does not exist displacement current or an *E*-field inside a perfect conductor. It is confusing the issue to discuss imperfect (copper) conductors when we are talking about the rudimentary fundamentals. The conduction current, as Dr Stockman knows, is only in the surface of the conductor (i.e. skin depth is zero).

J. Catt, M. F. Davidson, D. S. Walton

WIRELESS WORLD, AUGUST 1980

DISPLACEMENT CURRENT

In their reply to my criticism in the April issue, p.77, Messrs Catt and Davidson and Dr Walton are challenging me to a defence. They mysteriously read out nonexistent statements from my letter. As an example, I never implied that *D* is displacement current. Nor did I state that there is an *E*-field in a perfect conductor. And my illustration clearly shows two different forms of displacement current, one in a capacitor and the other in a conducting wire.

The worst misconception by the authors occurs with reference to their meaningless derivation, eq. (1) to eq. (8). They invent a "world devoid of displacement current", but with a TEM wave. Indeed, freedom from displacement current is their postulate for the derivation. After a number of mathematical manipulations, they arrive at the striking result: "See, no displacement current". How could there be any when the postulating statement forbids it? Worse, right under their final equation, they claim no displacement current, not realizing that the r.h.s. i.e. $\epsilon(dE/dt)$ is displacement current. The authors perform the amazing feat of having and not having displacement current at one and the same time. They borrowed my eq. (1) to provide the starting point for their derivation, but the net result is that my equation remains correct.

The disturbing fact about the authors' reply is that they picked out various minor details for scrutinization, carefully staying away from any comments on the main message of my letter, which was that as a means for elimination of displacement current, *the author's contraption of a transmission line model is a failure!* Remember the title of the original paper in *Wireless World*, December 1978, p.81, "Displacement Current – and how to get rid of it". The message of my letter was that they failed to get rid of it.

Their transmission-line model contraption just does not work, since the displacement current now appears in the model. The authors seem to agree about the failure of their model, because in the third paragraph of their reply they admit to the existence of dD/dt in a transmission line, with reference to the one shown in their Fig. 3. Twice, they back up their derivation by references to the July 1979 issue of *Wireless World*. Anyone still not convinced of the faiure of the attempt by Catt, Davidson, and Walton to get rid of displacement current would do well to read Dr Lago's excellent letter in that issue.

H. E. Stockman
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Mass., USA.

For almost thirty years I have reluctantly accepted the concept of displacement current. When your contributors Catt, Davidson and Walton proposed an alternative theory I was impressed. Here at last was a concept that was intuitively acceptable. It did not occur to me then that this would cause controversy. It seemed that those who wished to stick to the displacement current theory could do so without dissent. It was after all only an idea thought up to explain a paradox, and the paradox most satisfactorily disappears if we accept the idea of energy current and treat the capacitor as a transmission line (I. Catt *et al*). The fierce defence of the displacement current concept has however convinced me of the importance of establishing a sound fundamental theory. The fact that so much energy is being expended in trying to prove the unprovable, with such scant regard for logic, is in itself thought-provoking.

One recent attempt in your journal to justify displacement current (August 1979) beats all. After a page of general discussion Professor Bell says in effect that if *Wireless World* readers believe in the existence of electromagnetic waves then Maxwell's equations must be true! Then, after stating Maxwell's equations, he says that the right-hand side of the fourth equation would be zero without displacement current. He carefully shuns the heresy that the current implicit in the term dE/dt could be something other than that exactly defined by the Great Prophet.

But I have now fallen into the trap of nit-picking about Professor Bell's interpretation of Maxwell's theories and this can only lead to fruitless argument. Let me end with a question. Who would ever invent such a contrived and artificial concept as displacement current if it were not a necessity? Thanks to Catt, Davidson and Walton it is no longer a necessity.

K. E. Wilkinson
Hertford
Herts

The author replies:

The first point to dispose of is Dr Walton's red herring of Aristotelian philosophers and *linear* motion (November letters). I mentioned early speculation about the planets because Newton's theory of gravitation was that the same force accounted for objects "falling" to earth (the notorious apple!) and for planets describing *closed orbits* about the sun. The theory of gravitation then involves the conceptual difficulty of action at a distance, unless one prefers to postulate fields of force or the "curved space" of general relativity. Incidentally Newton was *not* the first to suggest that a body in motion would so continue if undisturbed: Hobbes in his book *The Leviathan* mentions that it was a subject for discussion whether this be so or not, and himself unhesitatingly chose Newton's answer. The difference between them is that Newton formulated the precise law and "proved" it by incorporating it in his complete system of mechanics which was supported by experimental evidence.

Everyone tends to believe what he wants to believe (Mr Wilkinson refers to "a concept that was intuitively acceptable"), but scientists accept the *discipline* of two tests of new concepts:

(1) A theory should be consistent with all the known evidence.

(2) It should need the minimum number of supplementary hypotheses.

I do not believe that Maxwell's electromagnetic theory has ever been faulted on experimental evidence: the point at issue is that the concept of displacement current is so intellectually repugnant to some people that they refuse to accept it. Some other ideas of modern physics are also difficult: for example, "tunneling" as in the Josephson junction and the representation of the electron as a packet of waves which may extend over a considerable space.

Are all such theories of modern physics to be rejected because they are not "intuitively acceptable"? The second test must then be applied to whatever theory is proposed as an alternative to Maxwell's. Now I do not know what the "energy current" proposed as an

alternative is (it surely cannot be defined by Poynting's vector, since that relies on Maxwell's theory of electromagnetism) but it would require some supplementary hypotheses to explain the electric and magnetic phenomena which accompany the supposed energy current. The most spectacular phenomenon is the production of an electric spark in air by a focused laser beam. Coming nearer home, the advantage of a loop aerial in the presence of some types of local interference (*Wireless World* July 1979) is predicted by the solution of Maxwell's equations. It is not an obvious result of a theory of energy current.

Turning to the issue of displacement current in capacitors (as distinct from radiation), the article by Joan Blomberg to which Dr Walton referred in his November letter is concerned with Maxwell's difficulties in arriving at a satisfactory definition of displacement current in *electrostatics* (without reference to electromagnetic radiation); and so it confirms my statement that displacement current was an inherent part of Maxwell's theory of electricity, not merely a device to complete a differential equation. As I stated in my article, others since have found it convenient or even essential in electrostatics.

Messrs Catt, Davidson and Walton stated that no-one had ever measured the inductance of a capacitor. Why, then, did we have non-inductive capacitors? There cannot be a magic dividing line in either frequency or electrode geometry between low-frequency capacitors which may be inductive and high-frequency capacitors which never have inductance. The use of a transmission line representation changes nothing because the equations for a transmission line are based on distributed *inductance* and *capacitance*. This approach has served very well, taking account of the dielectric, of electrode geometry, of losses in both and application to non-uniform transmission lines. There is no justification for departing from it.

To summarise, displacement current is not the only physical concept which is difficult to accept. Before logically rejecting it and everything that has been built upon it one would need a fully defined and comprehensive theory which had passed the two tests of scientific discipline.

Dr Walton commented that much of the content of my article can be found in any elementary text book on electromagnetism. Of course it can. The article was written on the supposition that there are many readers of Wireless World who have not studied such a book.

D. A. Bell

WIRELESS WORLD, OCTOBER 1980

MAXWELL'S EQUATIONS REVISITED

As mentioned in the May correspondence columns, we received a large number of letters commenting on Ivor Catt's article in the March issue. Our original intention was to present collectively the main points of all these letters. After discussions between the author and some of the correspondents, however, we finally decided to print one letter which was considered by an independent referee to be fairly representative. (This referee is a senior engineer in a large computer firm.) The letter chosen is followed by a direct reply and some general remarks by the author.

Regarding Mr Catt's latest article, "Maxwell's equations revisited" in the March issue, I feel that he should be relieved of some of his pseudo-mathematical delusions. For example, what exactly does he mean by the equation

$$\frac{\partial h}{\partial x}\cdot\frac{dx}{dt}=\frac{\partial h}{\partial t} \qquad (1)$$

One criticism is that dx/dt can only be used to represent the velocity of the train if x represents the x-co-ordinate of a *fixed point*

on it. Mr Catt originally introduced x and t as independent variables to define a point in space-time, so dx/dt is a meaningless quantity.

Also, if Mr Catt had really performed a "careful analysis" he would have had great difficulty in deriving equation (1) in the first place, as anyone with even elementary knowledge of partial differential calculus could tell him. Equation (2)

$$\frac{\partial H}{\partial x}\cdot\frac{dx}{dt}=-\frac{\partial H}{\partial t} \qquad (2)$$

falls into the same category of fallacies. Small wonder it never appears in the textbooks!

Mr Catt then goes on to say that "almost anything" is a solution to the equations

$$\frac{\partial E}{\partial x}=-\frac{\partial B}{\partial t} \qquad (3)$$

$$\frac{\partial H}{\partial x}=-\frac{\partial D}{\partial t} \qquad (4)$$

This, to put it mildly, is a slight exaggeration of the facts. It is a fact that a sinewave, or a number of sinewaves, is the solution of the equations *given the correct boundary conditions*. Mr Catt's train is also a solution of the equations but since it obeys a different set of boundary conditions it does not appear as a sinewave. More rigorously, the train profile can be considered as a Fourier series comprising an infinite number of sinewaves with different frequencies and amplitudes, and possibly also some exponential terms.

Having demonstrated the non-existence of any justification for the "theoretical" part of the article, I would like to ask the author if he has any justification for the abuse he proceeds to hurl at mathematicians in general. Mathematics is a tool for the scientist or engineer to enable him to concisely describe physical phenomena. Insight, or a "feel" for the phenomena, is built into the equations and a competent engineer should be able to "look inside" the equations and visualise what they represent. Visualisation of abstract concepts is more difficult but simply because mathematics is used as an aid in describing them does not make the theory "ludicrous and false".

Waveguides, antennae and the like are designed using Maxwell's equations, not by hit-and-miss methods, and behave as predicted by the mathematics. Electromagnetic theory is mathematical by its very nature and if Mr Catt abandons the mathematics he will be left with very little of any practical use.

R. C. Hayes
University of Liverpool

The author replies:
Equation (1) relates three things:

(a) the slope of a surface,
(b) its forward velocity,
(c) the rate of rise of the surface.

If the slope is 1 in 4, the forward velocity 10 metres per second, then the rate of rise of the surface is 2½ metres per second. This kind of

relationship is the stuff of which science and engineering is composed. I think Mr Hayes knows full well what (1) means, since he has studied A-level mechanics.

Equation (2) says that if an unchanging TEM wave moves forward at the speed of light, the gradient of H with forward distance is related to the gradient of H with time. If it is a fallacy, then what is the correct formula?

Or are we not allowed to relate $\partial H/\partial x$ to $\partial H/\partial t$ for a TEM wave?

Let Mr Hayes tell mechanical engineers to convert their trains into a Fourier array of sinewaves, and see how they react! Thank God mechanical engineers are too practical to be sucked into the kind of quagmire that permeates electromagnetic theory! I do not want to travel in a train with some exponential terms designed into or out of it! Would Mr Hayes recommend that the passengers be positioned so as to minimize their harmonic content?

Waveguides, antennae and the like are emphatically *not* designed using Maxwell's equations, any more than a tribal dance wins the battle that follows.

My successful pioneering attempts to interconnect high speed (1 ns) logic in Motorola in 1964 forced me to abandon all the maths that had grown like weeds to choke electromagnetic theory. A logic step is emphatically *not* a Fourier array of sine-waves, and you will run into all sorts of nonsense if you kid yourself that it is. Also, you can only successfully decouple the 5-volt supply to sub-nanosecond logic because it is untrue that capacitors have stray series inductance. The regular abandonment, at vast cost, of high speed logic systems during development will only cease if we can infiltrate some common sense into electromagnetic theory, and it stops serving merely as a favourite stamping ground for physically ignorant, fancy maths obscurantists. We must take the blarney out of electromagnetic theory.

The author also makes the following general remarks on the whole of the correspondence:

All twenty-two correspondents ignored the physics and concentrated on the mathematics. It seemed that whether Maxwell's equations mapped meaningfully and usefully onto reality mattered not. All that mattered was that the maths should be internally correct, or at least respected. An engineer like myself, who has sometimes worked as if through a blizzard of irrelevant, convoluted maths, takes the opposite view.

Some of the replies thought the minus sign should be there; some said it should not be. None noticed or contradicted my point, that the minus sign had no physical significance. (In fact it is an outgrowth of partial differentiation. Full differentiation has no minus sign, being a completely different operation from partial differentiation, in which the sign appears regardless of the nature of that which is being differentiated.

Always at a point on a surface in a three dimensional graph, the three slopes are related by

$$\frac{\partial z}{\partial x}\cdot\frac{\partial y}{\partial z}\cdot\frac{\partial x}{\partial y}=-1$$

The minus sign has nothing to do with electromagnetic theory. This contrasts with

$$\frac{dx}{dy}\cdot\frac{dy}{dz}\cdot\frac{dz}{dx}=+1$$

which is always true of the gradients of lines in two-dimensional graphs.)

I. Catt

C.A.N.

WIRELESS WORLD NOVEMBER 1980

DISPLACEMENT CURRENT

Following Professor Bell's article "No radio without displacement current" (August 1979 issue), I wrote a letter which appeared under the title "Displacement current" (November letters). A reply by Professor Bell to my letter was published in the same issue. I felt that this reply revealed misunderstandings of a fundamental nature regarding the points I was trying to make and I could not see how any useful purpose would be served by my responding to it. Since, however, Professor Bell has restated his arguments in the August 1980 letters it seems that I must reply.

My original letter contains the following two paragraphs:

"I understand that Aristotelians believed that a force was necessary to keep bodies in motion and that, in the absence of this force, the motion would cease. This theory led them into certain difficulties. For instance a spear once thrown, appeared to continue to move without a force being present. The philosophers rose to this challenge magnificently with a theory that air, displaced from ahead of the spear, rushed to the rear and generated the requisite force – the theory was saved. Unfortunately they missed the simple point first noted by Newton, that it is in the nature of a moving body to continue to move.

"In the same way I fear that Maxwell invented a complex explanation for a very simple phenomenon, i.e. that electromagnetic radiation, or energy current, moves at the speed of light – and that's all, because that is what energy current does. No mechanism invoking E producing H and H, in return, producing E is required."

I would have thought my intention was quite clear – it was to show, by analogy, how a faulty set of primitives can lead to problems in a theory which necessitate the introduction of ad hoc causality relations. In a similar way I believe that the causality relations alleged to reside in Maxwell's equations (i.e. changing magnetic field producing electric field and changing electric field producing magnetic field) are spurious. A moving body continues to move because that is what moving bodies do; an electromagnetic disturbance or energy current, of whatever distribution, continues to move because this is what energy currents do. In other words the statement "energy current travels at the velocity of light" is a primitive assumption in my theoretical framework which requires no further explanation. In my framework the moving energy current is the simple situation and 'static' electric and magnetic fields are composite.

Before I leave this point I must make two other observations. Firstly Professor Bell not only seems to misunderstand my argument but to compound this by not even having an adequate grasp of his original article, for he states in both the November 1979 and August 1980 replies that "I mentioned early speculation about the planets because Newton's theory of gravitation ....." My problem is that I can find no such mention of the planets in Professor Bell's article. True, he mentions Jupiter in the context of the propagation of radio waves from the vicinity of this planet, but nothing else.

Secondly, the relevance of Hobbes's *The Leviathan* seems a little dubious. I will admit that my statement that the principle of inertia was first noted by Newton is open to question – I would suggest that it was probably first noted by Galileo and enunciated by Newton – although it seems a little beside the point. Incidentally, I cannot locate the passage in *The Leviathan* which Professor Bell is referring to and wonder whether he in fact means some other work by Hobbes, possibly *De Corpore*. I would in any case be obliged if he could let me have a full reference. Since *The Leviathan* is a work of political philosophy it would be a strange place to make the kind of comments quoted by Bell – but who can tell with philosophers!

Several other points are raised by Professor Bell's letter. Before Maxwell's theory can be "faulted on experimental evidence" we require a definitive statement of that theory. Where is this to be found? Certainly not in Maxwell's *Treatise* since this involves views regarding the aether which would not be acceptable to modern physicists. Perhaps if someone could supply a definitive statement of Maxwell's theory I might be able to suggest some experimental tests.

Professor Bell states that he does not know what the energy current concept is or how it relates to the Poynting vector, yet this is set out in the article by Catt (see "The Heaviside signal," *W.W.* July 1979). It surprises me that, having stated his lack of understanding of the concept, and apparently not having seen the above-mentioned article, he still tries to apply it to loop antennas, etc.

It is extremely unfortunate that the displacement current debate has been cluttered by so many side issues. I feel great sympathy for the impartial reader of this correspondence who is attempting to decide which side of the debate has the greater insight into the subject. I am more or less resigned to the fact that it is impossible to debate the central issues of electromagnetic theory because of the high 'noise level' which is generated by those who defend the established view. Where do we go from here? As Professor Bell says, "Everyone tends to believe what he wants to believe" or, to quote from T. S. Kuhn, ("The structure of scientific revolutions," University of Chicago):

> "Max Planck, surveying his own career in his *Scientific Autobiography*, sadly remarked that 'a new scientific truth does not triumph by convincing its opponents and making them see the light, but rather because its opponents eventually die, and a new generation grows up that is familiar with it'.
>
> "These facts and others like them are too commonly known to need further emphasis. But they do need reevaluation. In the past they have most often been taken to indicate that scientists, being only human, cannot always admit their errors, even when confronted with strict proof. I would argue, rather, that in these matters neither proof nor error is at issue. The transfer of allegiance from paradigm to paradigm is a conversion experience that cannot be forced. Lifelong resistance, particularly from those whose productive careers have committed them to an older tradition of normal

science, is not a violation of scientific standards but an index to the nature of scientific research itself. The source of resistance is the assurance that the older paradigm will ultimately solve all its problems, that nature can be shoved into the box the paradigm provides. Inevitably, at times of revolution, that assurance seems stubborn and pig-headed as indeed it sometimes becomes."

Do we really have to wait for a new generation to grow up before we can countenance changes in the accepted theoretical structure? This is the real problem, not electromagnetism, relativity or mechanics, but how to create a forum in which proper discussion of fundamentals can take place.

D.S. Walton
CAM Consultants

Perhaps Professor Bell (August letters) really should have completed his application of the two "disciplines" of science to both the Maxwell and the Catt, Davidson, Walton theories. CDW's theory certainly has fewer hypotheses than Maxwell's (they only need to define what they mean by energy current). From their theory one can deduce Maxwell's equations (yes, and the famous $d\mathbf{D}/dt$ term, which is a mathematical quantity, not a "physical current") as well as Faraday's and Maxwell's laws of electromagnetic induction.

I don't believe Catt, Davidson and Walton have ever attempted to suggest that Maxwell's equations are incorrect, merely that they are at best mathematical devices exceedingly useful for setting university examination questions. They may or may not be correct on this point, but that, of course, isn't what everyone's supposed to be discussing (see the editorial in the May issue).

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